Mr. Carpenter further states that between July 28 and August 4, 1916, while on Mount Rainier, Wash., he observed each of the eight sunrises and sunsets, and there was a total absence of other than the usual twilight colors. He therefore infers that the dust cloud did not extend to this high latitude (47° N.).

In a letter of September 20 he forwards a note from Prof. A. E. Douglass, University of Arizona, relative to radiating shadows observed at that place on the underside of the dust layer. It appears that these shadows are first seen 16 minutes after sunset, and continue about 10 minutes, and were best observed on September 14 and 15. Prof. Douglass identifies them as shadows from mountain peaks or clouds in the range running south from San Diego, and about 300 miles from Tucson in an air line. From the angular height of the shadows he computes the dust layer to be from 12 to 15 miles above the surface.

It does not seem possible to connect this dust or haze with the haze that produced the brilliant twilight colors that were generally observed in the vicinity of Washington, D. C., at the end of July, and also at Lincoln, Nebr., at about the same time.[1] The pyrheliometric observations obtained at Santa Fe, New Mex., Lincoln, Nebr., Madison, Wis., and Washington, D. C., and summarized on another page, give no indications of unusual haze during August. Up to the date of writing this note the Weather Bureau has been unable to learn of a recent volcanic eruption of sufficient violence to cause a haziness of the upper atmosphere of the character observed. We shall be glad to receive further information relative to this interesting phenomenon.

The following is the substance of an additional note from Mr. Carpenter, under date of October 7, 1916:

It is reported from the Lick Observatory, Mount Hamilton, Cal., that red sunsets have been observed since the first week in August. On many nights in August and September the sky was rather thick, and the Milky Way did not stand out as prominently as usual. This and the red sunsets have been interpreted by the observatory to mean that the atmosphere has contained an abnormal amount of finely divided dust.

Red twilight glows have also been reported from San Bernardino and San Diego, Cal., and Phoenix, Ariz. At Tucson, Ariz., no red sunsets have been observed since the middle of September, but here at Los Angeles, in spite of unusually heavy rains during the first few days of October, they do not appear to have decreased in frequency. Whenever the mornings and evenings have been clear the sky has been suffused with a red glow.

In Switzerland.—Added significance is given the above observations by the following note quoted from the British Meteorological Office circular.[2]

Dr. Maurer, director of the Swiss Meteorological Institute, writes from Zurich that since the middle of July the atmosphere in the high Alps has shown noteworthy *optical deterioration*, indicated by the extension of the aureole round the sun, to as much as 140° in diameter at the end of August, and by a true brown Bishop's ring, visible on August 3 and 4. The cause of the deterioration is still in doubt. Corresponding phenomena in 1883–4, 1902–3, and 1912 were attributed to violent volcanic eruptions, but no reports of volcanic eruptions have come to hand this year. Whether or not the cumulative effect of gunfire in the course of two years is equivalent to that of a volcanic eruption there are no figures to show.

[1] *See* MONTHLY WEATHER REVIEW, July, 1916, 44:382. After the publication of the July REVIEW several correspondents in Virginia also reported brilliant sunsets at the end of July.—*H. H. K.*

[2] *Great Britain. Meteorological Office.* Meteorological Office circular No. 4 [London], Sept. 21, 1916. p. 4.

ATMOSPHERIC REFRACTION AT MOUNT HAMILTON, CAL.[1]

Aside from conditions which actually conceal objects or make the images so unsteady that accurate observation is impossible, the atmosphere is of importance to astronomy and geodesy because of its refractive power. Professor Simon Newcomb [2] writes as follows concerning atmospheric refraction:

The refraction of a ray of light by the atmosphere as it passes from a heavenly body to an observer on the earth's surface, is called "astronomical [refraction]." A knowledge of its amount is a necessary datum in the exact determination of the direction of the body. In its investigation the fundamental hypothesis is that the strata of the air are in equilibrium, which implies that the surfaces of equal density are horizontal. But this condition is being continually disturbed by aerial currents, which produce continual slight fluctuations in the actual refraction, and commonly give to the image of a star a tremulous motion. Except for this slight motion the refraction is always in the vertical direction; that is, the actual zenith distance of the star is always greater than its apparent distance. The refracting power of the air is nearly proportional to its density. Consequently the amount of the refraction varies with the temperature and barometric pressure, being greater the higher the barometer and the lower the temperature.

At moderate zenith distances, the amount of the refraction varies nearly as the tangent of the zenith distance. Under ordinary conditions of pressure and temperature it is, near the zenith, about one second [of arc] for each degree of zenith distance. As the tangent increases at a greater rate than the angle, the increase of the refraction soon exceeds one second for each degree. At 45° from the zenith the tangent is 1 and the mean refraction is about 58 seconds. As the horizon is approached the tangent increases more and more rapidly, becoming infinite at the horizon; but the refraction now increases at a less rate, and, when the observed ray is horizontal, or when the object appears on the horizon, the refraction is about 34 minutes, or a little greater than the diameter of the sun or moon. It follows that when either of these objects is seen on the horizon their actual direction is entirely below it. One result is that the length of the day is increased by refraction to the extent of about five minutes in low latitudes, and still more in higher latitudes. At 60° the increase is about nine minutes.

The atmosphere, like every other transparent substance, refracts the blue rays of the spectrum more than the red; consequently, when the image of a star near the horizon is observed with a telescope, it presents somewhat the appearance of a spectrum. The edge which is really highest, but seems lowest in the telescope, is blue, and the opposite one red. When the atmosphere is steady this atmospheric spectrum is very marked and renders an exact observation of the star difficult.

Again writing of the difficulties connected with this study, he says:[3]

There is perhaps no branch of practical astronomy on which so much has been written as on . . . [refraction] and which is still in so unsatisfactory a state. The difficulties connected with it are both theoretical and practical. The theoretical difficulties . . . arise from the uncertainty and variability of the law of diminution of the density of the atmosphere with height and also from the mathematical difficulty of integrating the equations of the refraction for altitudes near the horizon after the best law of diminution has been adopted.

In spite of the difficulties, however, all accurate position work demands that the observed positions of stars be corrected for atmospheric refraction. This necessity has led to the construction of "refraction tables" from which a correction for atmospheric refraction can

[1] *Comstock, G. C.* Reduction tables for the Lick Observatory III, IV, and V (1883) Univ. Cal. publ. Lick observ., 1:221-258 (Sacramento, Supt. State Printing, 1887).

Tucker, R. H. The refraction, *in* Meridian circle observations made at the Lick Observatory 1896-1901. Univ. Cal. publ. Lick observ., 6:150-155. (Sacramento, Supt. State Printing, 1903.)

Tucker, R. H. The refraction, *in* Meridian circle observations made at the Lick Observatory 1901-1906. Univ. Cal. publ. Lick observ., 10:14-17. (Sacramento Supt. State Printing, 1907.)

Crawford, R. T. On astronomical refraction. Univ. Cal. publ. Lick observ., 7 [1902-1911]: (part 6) 159-216, [1909]. (Sacramento, Supt. State Printing, 1913.)

Tucker, R. H. Diurnal variation in the refraction at Mt. Hamilton. Univ. Cal. publ. astron., Berkeley, 1913, 7:130-139. (Lick Observ. bul. 231.)

Tucker, R. H. The diurnal variation of the refraction. Astron. soc. Pacific publ., San Francisco, 1916, 28:69-73.

Recent observations on the diurnal change in the refraction at Lick observatory. Ibid., 28:199-200.

[2] *N[ewcomb], S.* Astronomical refraction. Encyc. Britannica, ed. 11, New York, 1911. 23:29.

[3] *Newcomb, S.* A compendium of spherical astronomy. New York, 1906, p. 223.

In this connection, especially for the Pacific coast mountains of the United States, see *Schott, C. A.* "Hourly values of the coefficient of refraction," *in* The transcontinental triangulation and the American arc of the parallel. Washington, 1904, p. 254-256. (U. S. Coast and Geodetic Survey, Special publ. No. 4.)

be obtained for a star at any apparent zenith distance.[4] In all cases it is necessary to assume that refraction introduces no errors of azimuth, although this is sometimes far from the truth.[5]

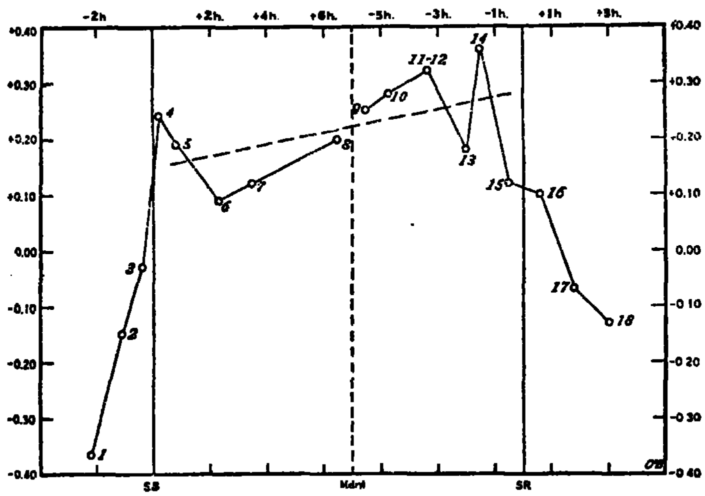

FIG. 1.—Corrections to the Pulkova refractions, for the Lick Observatory. SS = sunset; SR = sunrise. (After R. H. Tucker.)

Note the sudden fall in correction about 2 hours *after* SS, and again about 2 hours *before* SR.

Refined work at Lick Observatory and elsewhere has shown not only that the correction for refraction determined by the Pulkova tables is often too large but also that there is a diurnal variation in the refraction.[6] Figure 1[7] shows the march of the variation in refraction at Mount Hamilton based on observations during the years 1905 and 1906. The average variation is plotted with reference to the time of sunrise and sunset.

Partly because of the unsatisfactory condition of the refraction correction from both theoretical and practical considerations and in part because it was recognized that every observatory—particularly one situated at a considerable altitude—might present a special case requiring individual treatment, every observation of a standard star made at Lick Observatory has been so handled that the derived value of the latitude presents a contribution to the refraction correction. It has been shown from theoretical considerations that the standard Pulkova equations are applicable for atmospheric pressures as low as 850 millibars (25 inches).[8]

[4] *Bessel's Tables (Friedrich Wilhelm Bessel):*
Fundamenta astronomiæ. Regiomonti. In commissis apud Frid. Nicolovium 1818. Pp. 25-62.
Tabulæ Regiomontanæ reductionum observationum astronomicarum ab anno 1750 usque ad annum 1850 computatæ. Table 14. Regiomonti, Prussorum, 1830.
Pulkova Refraction Tables:
Tabulæ refractionum in usum Speculæ Pulcovensis congestæ Petropoli, 1870.
Tables de refraction de l'Observatoire de Poulkova. St. Petersbourg, 1905.
U. S. Naval Observatory Refraction Tables:
Refraction Tables (Bessel). Washington, April, 1887.
Refraction tables (Pulkova). U. S. Naval Obser. Publ., Ser. 2, Washington, 1904. 4:E30-E54. (Appendix 2).
Reduction tables for Equatorial Observations by C. W. Frederick. U. S. Naval Obser. Publ. 4:F1-F101 (Appendix 3). Washington, 1905.
Lick Observatory Refraction Tables:
Reduction Tables, Comstock, 1883. Univ. Calif. publ. Lick Observ. 1:221-258, Sacramento, Supt. State Printing, 1887.
Refraction Tables, Crawford (1907). Univ. Calif. publ. Lick Observ. 7:201-216. Sacramento, Supt. State Printing, 1913.
de Ball's Tables (L. de Ball):
Refraktionstafeln. Leipzig, Wilh. Engelmann, 1906. xiv, 18 p.

[5] *Campbell, W. W.* Elements of practical astronomy. 2d ed. New York, 1906. p. 33.

[6] See *Newcomb, S.:* Researches on the motion of the moon. Pt. 2, p. 14. U. S. Naval Observ. American Ephemeris and Nautical Almanac. Astron. Papers 9, pt. 1, Washington Govt. Printing Office, 1912.

[7] Univ. Cal. Publ astron., Berkeley, April 25, 1913, 7, pt. 6 p. 132 (Lick observ., Bul. 231).

[8] *Comstock, G. C.* Reduction tables for the Lick observatory (1883). Univ. Cal., publ. Lick observ., Sacramento, 1887, 1: 223-225. 1887.

Refraction anomalies related to sunrise and sunset.

The study of the refraction data when the anomalies were arranged by hours showed comparatively little system, although a seasonal influence was manifest. The data did show, however, a slight progressive change during the night. Much more system appeared in the anomalies when the data were arranged with reference to sunrise and sunset. There is a very rapid change within two hours of each of these two epochs. Mr. Tucker[9] finds that the effect may be considered due to the action of the sun while above the horizon in changing the atmospheric refraction from that computed for temperatures based upon thermometers exposed at the surface of the earth. The actual recorded temperatures and their changes up or down during the hours of observation had no direct influence on the general result.

That the differences are not the result of incorrect determination of air temperature has been shown by Crawford's careful study[10] of the temperatures in various parts of the observing room and of the air outside. The construction of the meridian-circle house is such that it is practically a large instrument shelter and all the temperature differences were found to be insignificant.[11]

As the greater part of all meridian work is done at night the discussion of daytime refractions is important only for fundamental work which must be carried through the 24 hours. The attempt has been made to eliminate all errors other than those due to the refraction correction. For south stars errors in the adopted standard declinations were eliminated by differential comparison. It is theoretically possible to eliminate errors in the assumed declinations of circumpolar stars by observing both culminations; but practically the two determinations are made under varying conditions, different nadir readings, different graduation errors, and widely different zenith distances. The course adopted, the only safe one, was to arrange the reduction of the observations in such a manner as to eliminate every error except accidental errors of observation, and these were diminished by the large number of observations reduced.

Besides the difficulty of making daytime observations at all, the accidental errors of such observations are much larger than those of night observations, which are made under much more favorable conditions. The south stars are so much more difficult to see because of their rapid motion and the increased atmospheric glare, that second-magnitude stars, even at moderate zenith distances, are impossible while north stars of similar brightness and altitude present comparatively little difficulty. Tucker finds that "In general from experience at three other important observing stations,[12] the daytime conditions at Mount Hamilton can be described as the worst of all the stations, while night conditions are often the best experienced at any of them." [13]

An effect of the refraction at Mount Hamilton noticed generally in daytime, and as yet unexplained, is that south stars are more steady than north stars when the wind is southerly and north stars are generally more steady when the wind is northerly.

[9] *Tucker, R. H.* The diurnal variation of the refraction. Astron. soc. Pacific publ., San Francisco. April, 1916, 28:72.

[10] *Crawford, R. T.* On astronomical refraction. Univ. Cal. publ. Lick observ., Sacramento, 1913. 7 [1902-1911]: (pt. 6) 164-165 [1909].

[11] *Reed, W. G.* Meteorology at the Lick observatory, MONTHLY WEATHER REV., June. 1914. 42: 339-345.

[12] Dudley Observatory, Albany, N. Y., 1879-1883; Argentine National Observatory, Cordoba, Argentina, 1884-1893; Southern Observatory, Carnegie Institution, San Luis, Argentina, 1908-1911.

[13] See above, footnote 9, op. cit., p. 73.

This discussion of sources of error due to real changes in refraction—the effect of which can be determined and accounted for—is of more importance from a meteorological and, probably, even from an astronomical point of view than the many discussions in present-day astronomical literature regarding the failure of methods of observation due to accidental refraction errors, to sluggish levels, and to various instrumental errors. It is, therefore, wholly appropriate that it comes from an observatory whose first director[14] was moved to write:

> The observatory is not primarily designed for a meteorological station. Its very exceptional situation, however, creates a responsibility on its part to engage to some extent in making * * * meteorological observation * * *. The elevated and isolated site of the observatory will render researches on astronomical refraction of especial value, and the disposition of buildings and instruments has been made with this end in view.—*Wm. G. Reed.*

ON THE ABNORMAL PROPAGATION OF SOUND WAVES IN THE ATMOSPHERE.[1]

By S. Fujiwhara.

[Abstracted for the Review, by *H. Bateman*, Ph. D., Govans, Md.]

1. Shape of the region of audibility.

Peculiarities in the shape of the region of audibility of the sound from an explosion have been noticed very frequently during the last few years and have been associated with various meteorological conditions. The present war has provided splendid opportunities for the study of the propagation of sound waves produced by cannonading, and several papers have been written on the subject. In Japan the frequent explosions and eruptions of Mount Asama have provided even better opportunities for investigation and Japanese scientists have collected some very valuable information and made systematic observations. The material thus obtained has been studied mathematically by S. Fujiwhara in two able memoirs in which he shows that important information with regard to the structure of the atmosphere can be derived from a knowledge of the shape of the region of audibility. Some interesting types of regions are shown in figures 1 to 6.

A brief account of Fujiwhara's first memoir has already been given in this Review (May, 1914, **42:** 258–265). In his second memoir the author uses his mathematical results to obtain an idea of the shape of the region of audibility for each of the five types of atmospheric structure described by C. J. P. Cave in his book The Structure of the Atmosphere in Clear Weather. These are:

(*a*) "Solid" current, in which the wind remains steady in both direction and velocity in the upper layers.

(*b*) Continued increase of velocity beyond that of the gradient wind.

(*c*) Decrease of velocity in the upper atmosphere.

(*d*) Reversal or a great change of direction in the upper layers.

(*e*) An upper wind blowing out from a distant low-pressure center; frequent reversal in the lower layers.

For all the cases in each class Fujiwhara has examined whether a discontinuity of the region of audibility of an explosion can occur or not; his results are shown in Table 1.

Table 1.—*Classification of the regions of audibility about an explosion center for the different cases of atmospheric structure described by Mr. Cave.*

Type.	Number of cases.					Total.
	a.	*b.*	*c.*	*d.*	*e.*	
N_t	30	48	27	34	36	175
N_d	0	21	0	20	23	64
N_d/N_t	0	0.44	0	0.59	0.64	0.37

Note.—N_t denotes the total number of cases in each class; N_d, the number of cases in which discontinuity is to be expected.

Thus, if the region of audibility is discontinuous the winds in the upper atmosphere can not belong to classes *a* or *c*, *so long as horizontal homogeneity of the atmosphere is assumed.* In nearly all cases greater ranges of rays correspond to smaller gradients of wind velocities—air temperatures and the inclinations of the rays at the start being assumed as given. Since the direction of the axis of the region of audibility coincides nearly with that of the relative wind velocity at the height where the reflection takes place (see §3, eq. (3)), we can get a rough idea of the wind direction in the upper atmosphere from a knowledge of the surface wind and the direction and range of the regions of audibility.

In the first memoir the author pointed out that the occurrence of the detached region of audibility, i. e., an abnormal region, was closely connected with the existence of powerful cyclones. Many cases given in the present paper, however, are not in keeping with the above conclusion. The cases given in the first paper, however, occurred chiefly under weather conditions of the winter type. Now in winter the direction of the monsoon in Japan is northwesterly and no local depression of importance occurs over central Japan. Thus the region of audibility must continuously extend toward the east or southeast under the normal condition of winter. But when a powerful cyclone approaches, the above condition is disturbed, and detached regions of audibility may be detected. In the summer months the direction of the monsoon is southeasterly, and the development and passage of a local depression over central Japan is a daily phenomenon. The direction of the upper wind due to this depression, whose height above sealevel is comparatively small, about the same as that of Mt. Asama, can by no means coincide with that of the monsoon, and hence detached regions of audibility may occur. When a powerful cyclone approaches from the west, we may have abnormal cases in which no detached region can be detected or in which one is found in a direction other than westerly. In the period of transition from the weather of winter to that of summer, or vice versa, the direction of the wind of monsoon type is not confined to the northwest or the southeast, but can be anywhere between the northwest and southeast on the north side. In these periods the energy of the monsoon becomes less and the effect of cyclones or other meteorological elements on the phenomenon of the propagation of sound waves can easily become predominant.

The mathematical theory is worked out on the assumption that the atmosphere is uniform in each horizontal plane. There must also be further abnormalities of propagation when the uniformity is broken by the presence of floating sheets or masses of cloud in which the temperature may be different from that of the surrounding air and when a Helmholtzian wave exists at the boundary of two layers of the atmosphere with different velocities

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[14] [*Holden, E. S.*]: Description of the meteorological instruments. Univ. Calif. publ. Lick observ., 1:78 Sacramento, Supt. State Printing. 1887.

[1] *Fujiwhara, S.* On the abnormal propagation of sound waves in the atmosphere. Second part. Bull., Central met'l. obs'y. Tokyo, Japan, 1916, 2, pt. 4. pl., 32 p. 27 lith. 4°.